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# Overview of the LHCb calorimeters ☆

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ABSTRACT

LHCb, one of the four LHC experiments, is dedicated to the study of CP violation and rare decays in the B meson sector. It aims at completing the understanding of the quark flavor physics and at revealing signs of new physics beyond the standard model. The goal of the LHCb calorimeter is twofold. On the one hand, the calorimeter system has to provide a fast response for the first level trigger (L0) on the nature of the meson decay. Thus, the scintillator pad detector and the preshower provide a good $\gamma$/ charged particle and electron/$\pi^0$ separation and the electromagnetic and hadronic calorimeters give a fast transverse energy determination. On the other hand, it provides offline precision measurements and particle identification.

The calorimeter system consists of four sub-detectors. They are described in the first section, emphasising the technical choices and the similarities among those components. The second part concerns the monitoring and calibration tools and procedures that will be applied to have a satisfactory running of the detector.



## 1. Introduction

LHCb, one of the four particle physics experiments at the Large Hadron Collider at CERN, will perform studies of CP-symmetry violation and rare decays of B hadrons. It is a single arm spectrometer with a forward angular coverage motivated by the fact that at high energies both quarks from the $b\bar{b}$- pairs are predominantly produced at small angles with respect to the beam. At the nominal luminosity, $\mathcal{L} = 2 \times 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, $10^{12}$ $b\bar{b}$- pairs should be produced at the experiment interaction point in a year of data taking ($10^7$ s).

LHCb [1,2] consists of a magnet, a vertex locator, a tracking system, two ring imaging Cherenkov detectors, a calorimeter and a muon system. The main purpose of the LHCb calorimeters [3] is the selection and identification of hadrons, electrons and photons and the measurement of their energies and directions, both at the first trigger level and for the offline reconstruction. Four sub-detectors are associated to perform such identification: a scintillating pad detector (SPD) and a preshower (PS) allow to tag charged particles and to determine their electromagnetic nature; they are followed by an electromagnetic (ECAL) and a hadronic (HCAL) calorimeter. The calorimeter system is used at the first level trigger (L0) of LHCb by providing high transverse energy electron, photon, neutral pion and hadron candidates. The response of the calorimeter system has to match the accelerator frequency and provides a measurement at 40 MHz. The data are pipelined in the front-end electronics waiting for the L0 decision that combines the information from the calorimeter, the muon chambers and the pile up veto. Finally, the data are read out and sent to the CPU farm of the High Level Trigger (HLT) of LHCb at an average rate of 1 MHz.

## 2. Design of the LHCb calorimeter system

### 2.1. The scintillating pad detector and the preshower

The four calorimeters are wall-like structures divided into two halves which may be open and fully taken out of the acceptance. The first calorimeters seen by the particles incoming from the interaction point are the scintillating pad detector and the preshower. Their design is very similar and consists of two scintillating vertical planes made of 6016 pads. A 2.5 radiation length lead sheet is sandwiched between the two sub-detectors. This lead converter allows to initiate the electromagnetic showers so that electrons and photons deposit a sizable amount of energy in the PS. Charged particles leave in the SPD a minimum ionising particle (mip) signal which is detected while photons do not interact. Combining the SPD and the PS information with the cluster position reconstruction of the ECAL gives a determination of the nature of the electromagnetic particle interacting with the calorimeter system. This technique is used offline but also at the first level trigger of LHCb to tag high transverse momentum

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**Table 1**
The requirements to the LHCb calorimeter system.

| Sub-detector | SPD/PS | ECAL | HCAL |
|---|---|---|---|
| Number of channels | 6016 each | 6016 | 1488 |
| Lateral size ($m^2$) | $6.2 \times 7.6$ | $6.3 \times 7.8$ | $6.8 \times 8.4$ |
| Longitudinal depth | $180\,mm - 2.5X^0 - 0.1\lambda_I$ | $25X^0 - 1.1\lambda_I$ | $5.6\lambda_I$ |
| Basic requirement | 20/30 photo-electrons per MIP | $10\%/\sqrt{E} \oplus 1.5\%$ ($E$ in GeV) | $80\%/\sqrt{E} \oplus 10\%$ ($E$ in GeV) |
| Dynamic range | 0–100 MIPs—1 bit (SPD), 10 bits (PS) | 0–10 GeV $E_T$ | 0–10 GeV $E_T$ |

hadron, electron, photon and pion candidates, characterising a high mass B meson decay. Table 1 gives the main requirements to the LHCb calorimeter system.

The PS and SPD have a segmentation that varies with respect to the distance to the beam pipe, the cell sizes matching the ECAL cell size in order to make a projective system pointing to the LHC beam collision. The SPD/PS cells are scintillator pads grooved and holding an helicoidal wavelength shifting fibre (WLS). The light is propagated by clear fibres to multi-anode photo-multipliers (MAPMT) located in boxes above and below the SPD/PS walls and containing the very front-end electronics in charge of the shaping and for the SPD only, also of the sampling of the signal.

The SPD very front-end provides to the front-end electronics a binary information corresponding to the amplification and integration of the charges collected from the MAPMT. After pedestal subtraction and spill-over correction, the signal is compared with a threshold loaded by the slow control of the experiment. The output of this comparison is sent to the front-end electronics on a differential line.

The PS has an energy range of 100 mips. The signal of its MAPMT is also shaped and integrated on the very front-end. But unlike the SPD, the differential analog output is sent on 27 m long twisted pairs to the PS front-end boards housing a 10 bit ADC where the pedestal, spill-over and integrator gain corrections are applied.

Both the SPD and PS rely on a similar technique to measure the MAPMT signal and based on two parallel interleaved integrators running at 20 MHz per channel, one being read out and reset while the other is integrating the pulse.

The overall performances of the SPD and PS system have been determined during the commissioning of the detectors that is taking place since a couple of years and are fully satisfactory. The noise is estimated to be of the order of 3 mV for the former (a mip producing 100 mV in average), the channel offset being distributed around $-70$ mV with a spread of 70 mV. The noise of the PS is reduced to 1.2 ADC count (a mip corresponding to 10 ADC). Its pedestal is centred at 140 ADC counts with a maximum of 300 saving the expected dynamic range. The SPD and PS detectors are built around a very front-end and a front-end which are located from 20 to 30 m apart. This leads to stringent timing constrains on the design and to the integration of degrees of freedom to compensate for the cable lengths and to accurately sample the signals at the level of the front-end boards. The corresponding parameters have been intensively worked out during the commissioning to make a robust system.

### 2.2. *The electromagnetic and hadronic calorimeters*

The ECAL and HCAL are two wall-like calorimeters with a variable segmentation that fit the particle multiplicity. They have the same electronics, the main difference between those detectors is in the design of the modules. The ECAL is a shashlik system, each module consisting of 66 layers of scintillator (4 mm) and lead (2 mm) corresponding to one, four and nine cells of $12 \times 12, 6 \times 6$ and $4 \times 4\,cm^2$, respectively, in the outer, middle and inner areas defined by the distance of the cells to the beam pipe. The HCAL is made of 26 modules of iron and scintillator tiles whose light is also transported by WLS fibres and readout by 1488 photo-multipliers dividing the detector in cells of $26.2 \times 26.2$ or $13.1 \times 13.1\,cm^2$ in the outer and inner regions, respectively, the previously defined middle zone being merged here with the inner one. WLS fibres cross longitudinally the modules of the ECAL and HCAL to collect and propagate the scintillator light to photo-multipliers powered by Cockcroft–Walton bases. Both, the ECAL and HCAL PM high voltages are adjusted so that the measurement is directly performed in transverse energy, which is the most relevant quantity to trigger on.

The ECAL and HCAL photo-multiplier pulses are clipped in order to be fully contained in 25 ns (and prevent any further spillover) and sent to the front-end electronics located on the calorimeter platform. Unlike the SPD and PS, here the number of photo-electrons is such that the statistics loss due to the clipping is irrelevant. On the front-end board, the signal is shared in two paths: the first one feeds the negative input of a differential buffer, the second one feeds the positive one after a 25 ns delay. The integrator collects the output of the buffer and presents a tension increasing up to a plateau 4 ns wide corresponding to the integration of the first path. The delayed integration of the second path permits to perform a noiseless reset of the integrator. The clock of the 12 bit ADC of each channel is linked to a robot clock allowing to adjust the phase of the sampling with the timing of the plateau which may depend on the high voltage applied on the PM, the time of flight of the particles incoming from the interaction point and the cable length spread. An overall dispersion of up to 6 ns is foreseen which may be fully corrected.

The trigger is based on the existence of high transverse energy deposits. The front-end electronics identify them by summing the $E_T$ converted from 12 to 8 bits on $2 \times 2$ cell towers. This procedure requires data exchanges between front-end boards in a single crate, through the backplane and sometimes also in between different crates with cables. At a first stage, the determination of the list of high $E_T$ candidates is done per half crate (roughly 3.5% of the surface of the ECAL). The location of the electromagnetic calorimeter deposits is sent to the SPD and PS system that provides the corresponding and necessary information to determine its nature. In parallel, 4 HCAL candidates are formed from the HCAL and ECAL cell signal sums. Only one of each of the types photon, electron, neutral pion and up to 4 hadron candidates emerge at this first stage. The following step is performed in the counting room, in the safe area of the LHCb cavern and merge the previous data to identify the highest $E_T$ candidates for the full calorimeter system. Moreover, the SPD provides its total multiplicity to refine the trigger decision.

Like the SPD and PS, the electromagnetic and hadronic calorimeters have been intensively commissioned since a few years. RAM patterns were loaded in the digital electronics, pulse tests have been injected right at the level of the input signal cables or LED pulses were used (see below). This permitted to control the detector cable signal connections and to check the functioning of the full electronics chain. Although the LHCb detector geometry is